Paul B. Sears' Contributions to the Development of Paleoecology

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Abstract. Paul B. Sears laid the foundation for both the methodology and many of the major research questions that concern paleoecological research in North America and globally. Using sediment records mostly from Ohio as a starting point, he investigated the relative ages of glacial geomorphic features and the Ohio postglacial climate record. From there using his own and other records he investigated rates of sedimentation, regional sequences of revegetation after final deglaciation, rates of vegetation change, climatic interpretation of that change and the possible synchroneity of the North American and European climatic histories. Foundational early papers focused on the methodology and taxonomy of pollen analysis and the use of early land-survey data to reconstruct the vegetation record prior to European settlement and agricultural development. The latter was a critical strategy to identify modern climate analogs for fossil pollen assemblages. He also fostered mechanisms for international and interdisciplinary research communication. The field of paleoecology—the record of past environmental and climate change—was once esoteric. Today the ecological meaning of documented changes through time is one of the keys to understanding the consequences of today's rapid global climate change.

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INTRODUCTION

Ecology was the central interest of Paul B. Sears' professional life. Understanding an ecosystem includes understanding its history. Today the term paleoecology refers to the process of reconstructing the history of an ecosystem by examining as many facets of an increasingly wide variety of sedimentary/accretionary records as possible. Sears used pollen analysis data of bog sediments as a tool, as a means to reconstruct past vegetation and to infer climate.

Briefly stated, pollen analysis is based on pollen production, distribution and morphology. Many dominant plants in an ecosystem produce large quantities of pollen. Wind transports much of the total pollen produced and, as a result, some is deposited in basins such as lakes and bogs. Pollen grains produced by all members of a family or genus have a distinct morphology allowing identification, at these taxonomic ranks, of the plants producing that pollen. Finally, pollen "embalmed", to use Sears' term, in sediment is chemically resistant to decay and, consequently, can be recovered. Pollen recovery involves removing a stratigraphic sediment core from a basin, taking samples at regular intervals throughout the core, extracting pollen from them and making systematic counts using a microscope of the various taxa at each interval. Three key assumptions guide interpretation of the results: (1) relative frequencies of deposited pollen grains reflect the relative frequencies of the plants that produced them; (2) relative frequencies of the plants are related to climate gradients; and (3) the autecologies of dominant plant taxa that produced the pollen record have not changed significantly since the pollen was deposited.

In 1969, as a new graduate student in palynology under Dr. Alan Graham at Kent State University, I was instructed to read the classical papers in North American palynology. While only a few post-1960 papers related to Ohio, the older work of Paul B. Sears and John Potzger and their students was abundant. Initially I discounted the value of the older research done with marginally acceptable samplers for taking cores, no system for dating (pre-radiocarbon), crude sample preparations, microscopes that were hard to use and few counts of pollen of grasses and other herbs. How valid were their conclusions under these conditions? Despite the limitations of the equipment and methods used to produce the data for his research papers, I came to appreciate that Sears was one of the most insightful scientists of his time. The papers that he and his students published between 1929 and 1960 (mostly 1930-1950) laid the foundations of the modern field of paleoecology. Their early pollen analysis studies addressed questions that are still being intensively examined.

This article discusses Sears' contributions to the basic research questions and methodology of paleoecology and the importance of this field to our understanding of global climate change.

CONTRIBUTIONS TO PALEOECOLOGICAL RESEARCH

Sears had long been interested in the sources of plant taxa considered locally relict or disjunct, and his work with mapping vegetation at the time of European settlement (Stuckey, this volume) was part of his research in that context. If vegetation and climate were different in the past, then the presence of these taxa in unusual locations would not be inconsistent but rather would have an historical cause. Earlier Gleason (1922) postulated a past time of expanded prairie and greater warmth to explain eastern distributions of western prairie grasses (Stuckey 1990). This hypothesis led to Sears' desire to know climate and vegetation history of the forests and prairie patches. In 1925, when he became aware of the growing European scientific literature reconstructing past vegetation and climate using pollen records from peat deposits, he immediately recognized that the method was tailor-made for application to the North American questions. Sears first tried the method with Charles Olmsted in 1925, on muds from Lake Okoboji, Iowa (Stuckey 1990).

Sears used this new tool of pollen analysis to address a series of fundamental questions dealing with glacial history, vegetation and climate change—topics that are still current and central to the field of paleoecology. Such pioneering interdisciplinary thinking and research led the way for broad-based approaches to ecological reconstructions.

Ages of Glacial Deposits

In 1928 and 1929, Phyllis Draper, one of Sears' students, published the first two pollen diagrams from Ohio (Draper 1928, 1929). The first paper was a statement about the use of the technique. The second paper addressed estimating the difference in basal age between a

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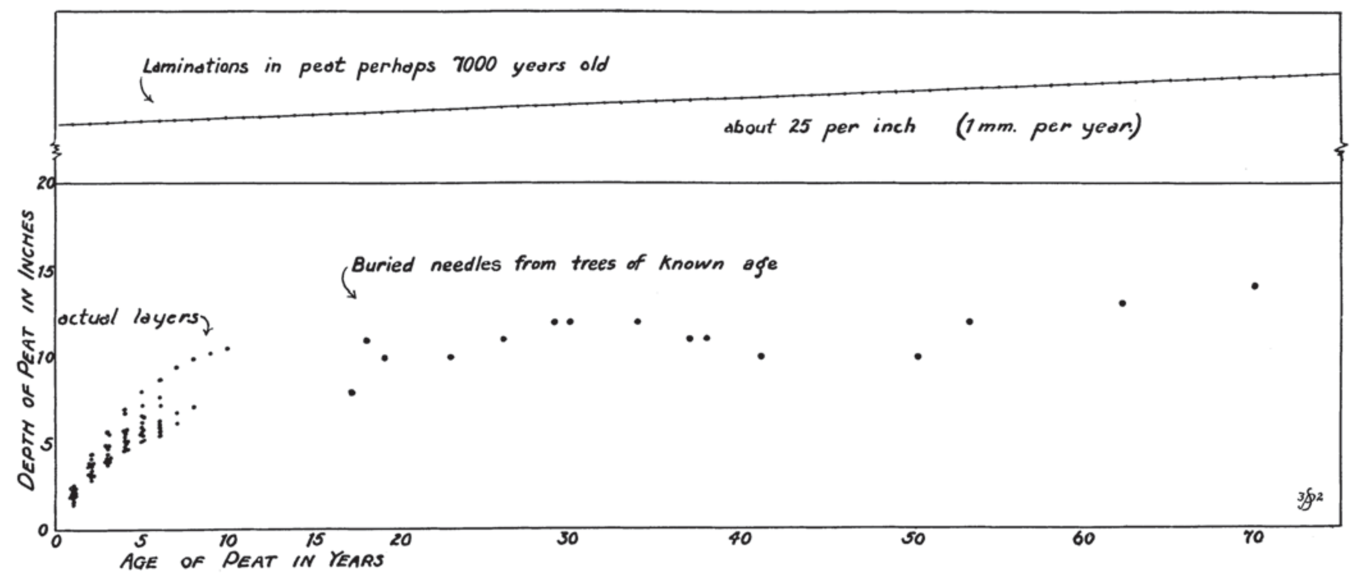
moraine system and the Lake Erie shore in northern Ohio. The project was not successful because of the lack of accurate dating techniques and a small difference in age between these two features. We still understand the retreat sequence of glacial ice from the Midwest only in outline. We also do not understand well the relationship between moraine formation and small climate shifts. In 1990-91, the author worked with Dr. Thomas Lowell of the University of Cincinnati at Stage's Pond, a very deep site just south of Columbus and quite near the glacial border. Lowell is studying the history of ice fluctuations in western Ohio between 25,000 and 15,000 years before present (ybp). Dating of the basal sediments at Stage's Pond and the climatic record contained in the pollen deposits are two of the problems addressed by this work.

Sedimentation Rates

Sears understood the need to date sedimentary records (Sears and Janson 1933). Using a bog site in Michigan with laminated peat, he and his student implemented a creative approach to the problem by attempting to estimate the changing "shrinkage" rate down the length of a core (Fig. 1). First, they looked for the first occurrence of *Picea* (spruce) and *Larix* (larch) needles in peat cores taken from the base of isolated trees that had been aged by increment cores to get an age estimate of an amount of deposit. Then they dissected a core from an open area. In the top 15 centimeters (6 inches), they could detect 9 layers that they presumed were annual. Then they looked for the first occurrence of *Picea* and *Larix* needles in peat cores taken from the base of isolated trees that had been aged



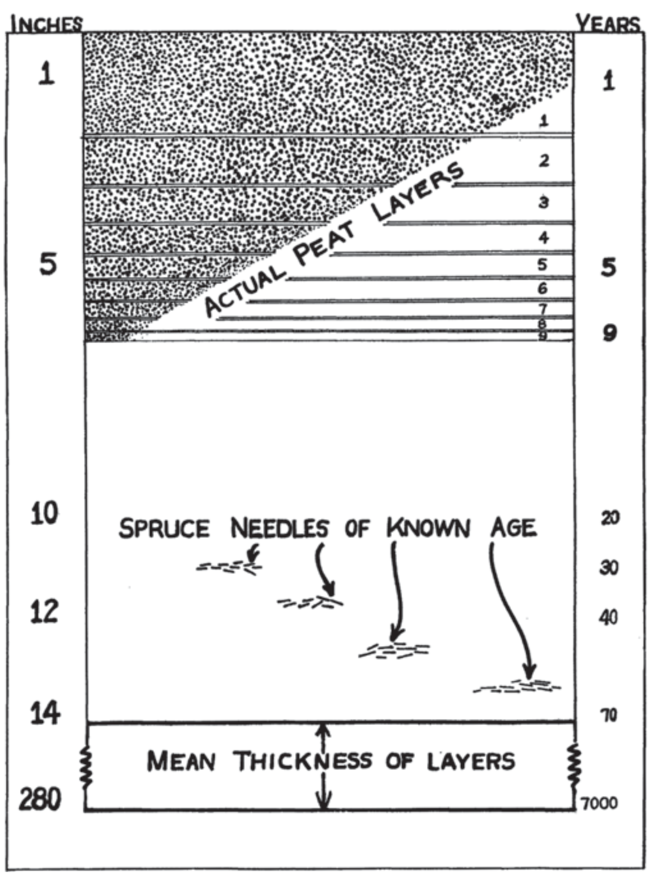


Figure 1. Top: Rate of increase in thickness of peat deposits with age. Bottom: Diagram showing actual rate of shrinkage for the first 9 years (Sears and Janson 1933). Copyright permission of publisher granted.

by increment cores. Below 38 centimeters, the peat consisted of alternating/interwoven layers of algal "jelly" and Cyperaceae (sedge) leaves, which, when frozen, appeared to have about 25 laminations per inch. They also accomplished fine dissection of these layers, and report that "Moreover, the mean distance between such layers of pollen as could be found in sections was about 1/25th of an inch" (Sears and Janson 1933). They concluded that an exponential function could be calculated to fit the data, but with significant measurement error, such a calculation was not justified. Research into the problems of peat growth rates continues (Clymo 1991). Several graduate students in the Paleoecology Research Training Group at the University of Minnesota have worked on the information from the detailed study of laminated lake sediments.

Postglacial Revegetation Sequences

Sears' paper on *Postglacial Migration of Five Forest Genera* (Sears 1942a) focused on the question of postglacial change on the large geographic scale of eastern North America. The genera he considered were *Quercus* (oak), *Tsuga* (hemlock), *Carya* (hickory), *Fagus* (beech) and *Tilia* (basswood). He asked, What was the sequence of reestablishment of these taxa in newly unglaciated areas? Were there any obvious migration routes? What climatic signals can be derived from these sequences?. He surveyed 111 published and unpublished pollen records from New England, New York, Pennsylvania, the Great Lakes states and southeastern Canada. He plotted the sequence of occurrence of each of the five taxa on maps of the area (Fig. 2) and then considered the results as answers to the questions. Those results are limited in that he had no good way to date the records, and he considered single-grain occurrences as evidence of presence of a taxon. However, he showed clearly that *Quercus* (oak) appeared early in the late-glacial time, that *Tsuga* (hemlock) migrated from east to west, and that *Fagus* (beech) and *Tilia* (basswood) arrived somewhat later. The arrival of *Carya* (hickory) was somewhat confusing. The availability of hundreds of radiocarbon-dated sites enhances the detailed expansion of this basic method. Published examples are the migration maps of M. Davis (1981, 1983) (Fig. 2), digital database generated maps of Webb and his colleagues (Webb 1981, Webb and others 1987) and studies of the revegetation of New England (Davis and others 1980, Davis and Jacobson 1985). "Pollen movies" showing pollen frequency change of individual taxa through the past 20,000 years are available at http://www.ncdc.noaa.gov/paleo/pollen/viewer/webviewer.html. The landscape interpretations of these changes are at: http://www.ncdc.noaa.gov/paleo/vegmap.html.

This research elucidated some fascinating and important aspects of vegetation history that should be incorporated into any theoretical interpretations of the flora of a region. First, across eastern North America, the forests have changed over time. Most modern assemblages formed from 5,000 to 500 ybp. Second, various arboreal taxa clearly behave individually in relation to climate. Because climatic changes occur continuously on 100 to 1,000-year time scales, current research raises questions concerning the formation and maintenance of biotic communities and ecosystems. Third, during the postglacial periods, plant communities existed that have no modern analogs. One of the major questions argued in paleoecology today is how much of the pollen record reflects climate and how much reflects migration (Webb 1986). The controversy becomes more intense when intraglacial fluctuation records are considered, but not for records of the 100,000 year glacial/interglacial cycles.

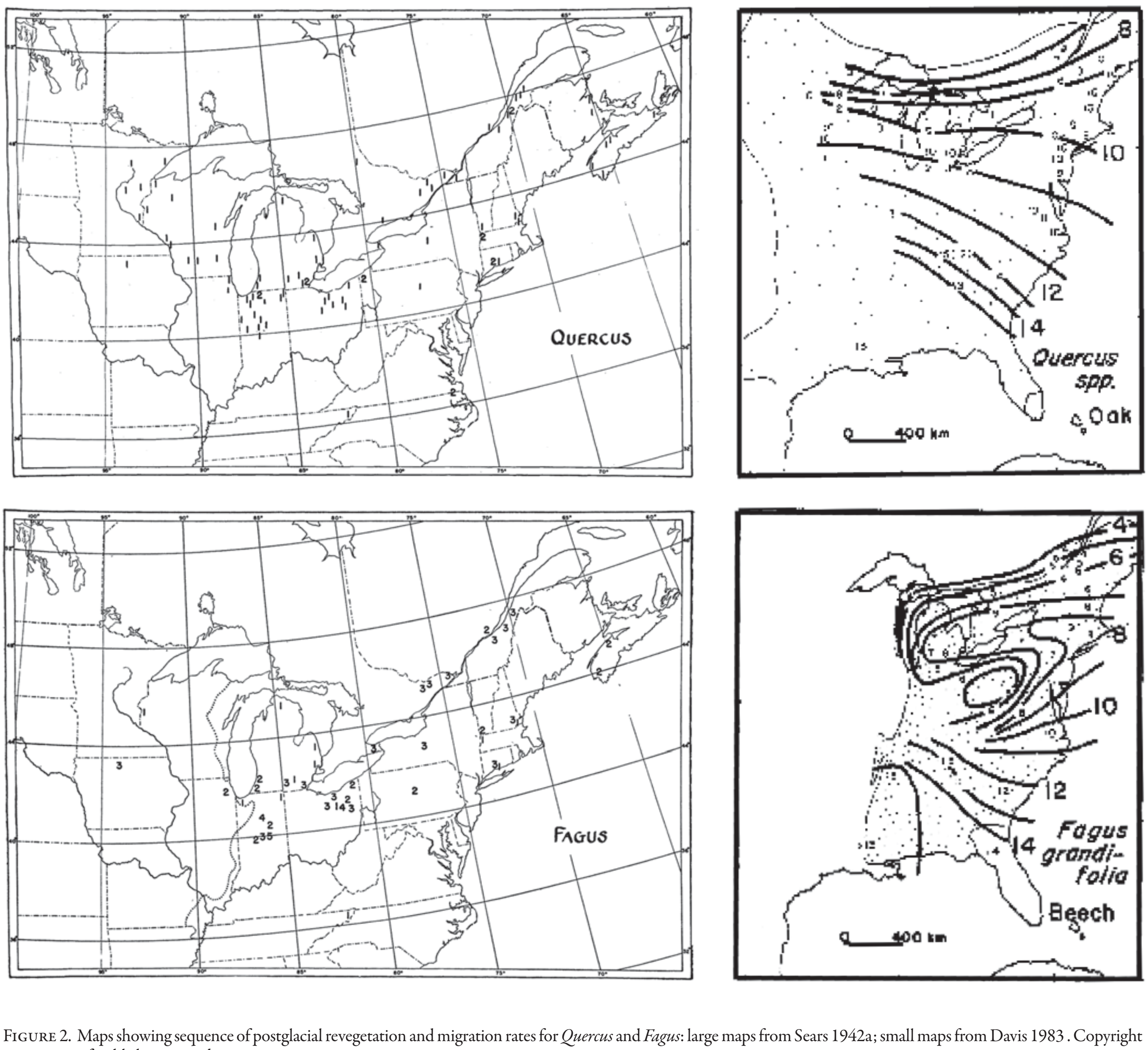
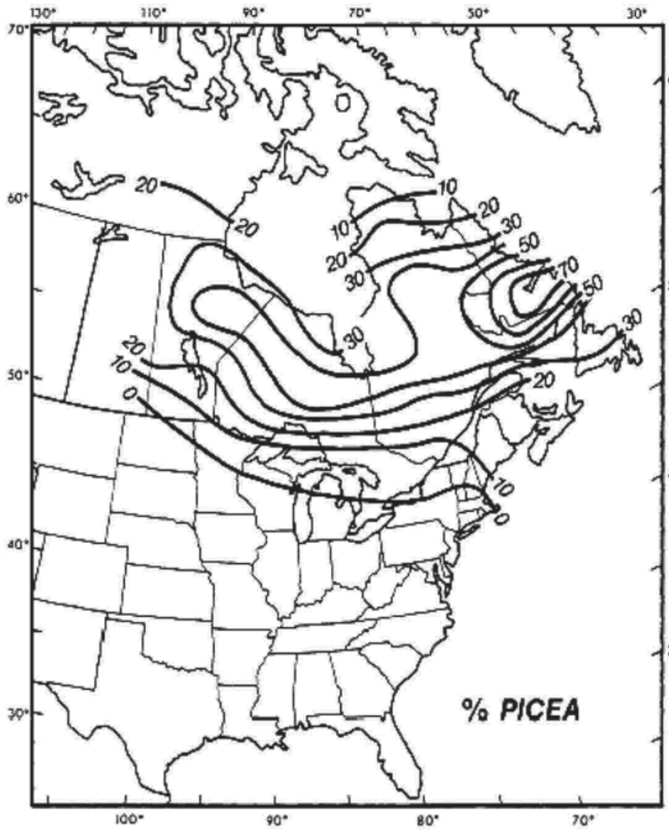
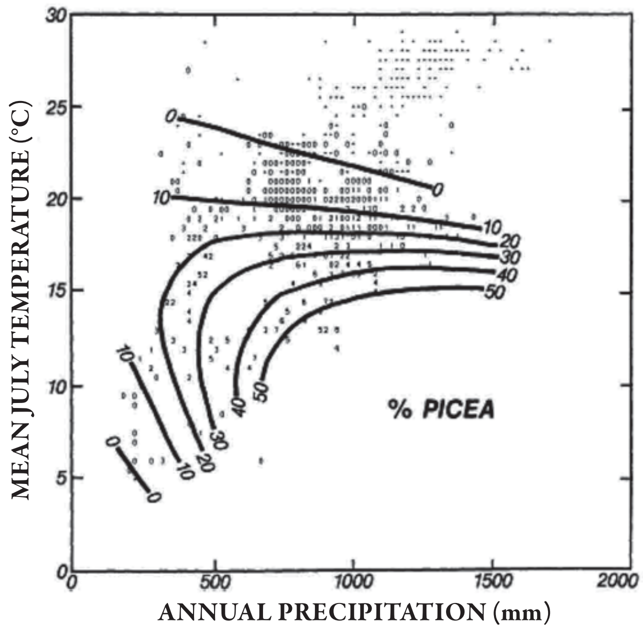


FIGURE 2. Maps showing sequence of postglacial revegetation and migration rates for *Quercus* and *Fagus*: large maps from Sears 1942a; small maps from Davis 1983 . Copyright permission of publisher granted.



Picea (spruce) pollen percentage



Picea (spruce) pollen percentage

FIGURE 3. Example of a response surface graph: *Picea* (spruce) (Bartlein and others 1986). Copyright permission of publisher granted.

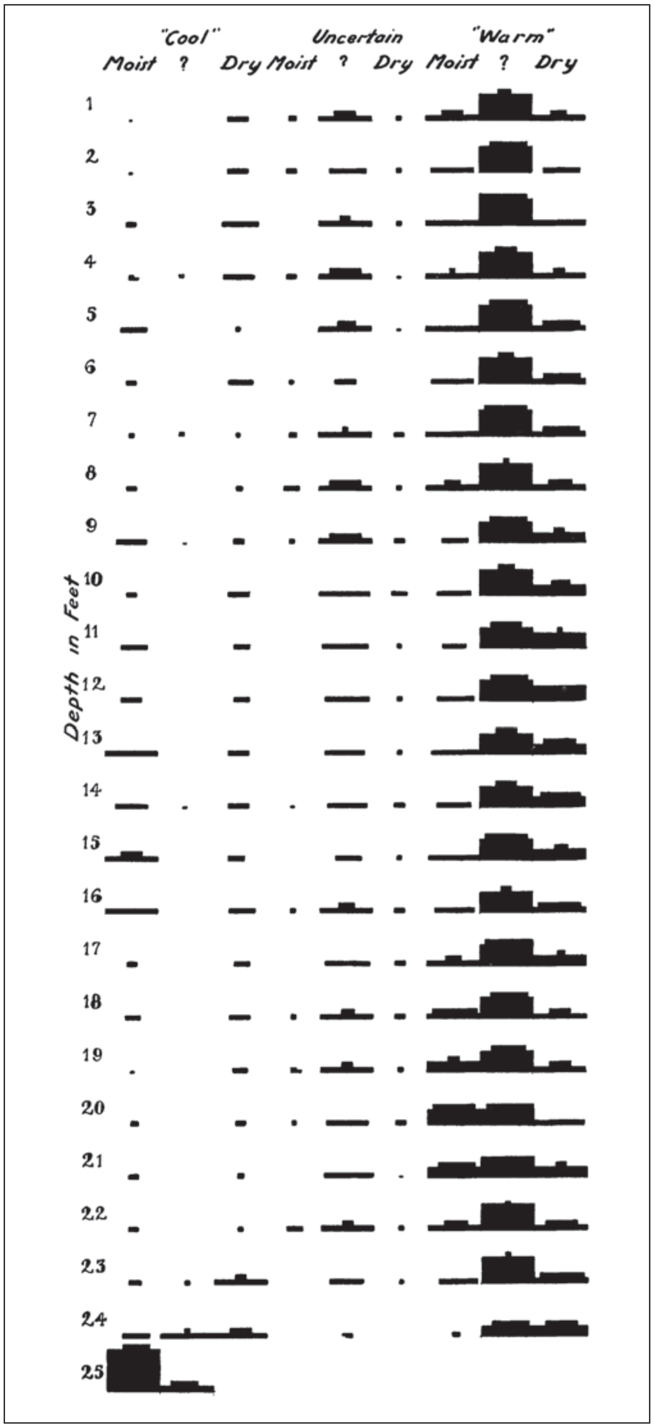
Response suface analysis: Left. Pollen frequency surface data plotted geographically (Fig. 3(a) Bartlein and others 1986); Right: pollen frequency surface data plotted against both mean July temperature and annual precipitation. (Fig. 3(b) Bartlein and others 1986). Note that highest spruce pollen frequencies occur where mean July temperature is between 10° and 15°C and precipitation is 800-1500 mm per year.

Climate Reconstruction

The above discussion leads back to the key question that first intrigued Sears. Was there a postglacial warm period with eastern expansion of the western prairies that accounts for the presence of prairies and their characteristic taxa in Ohio? For all the pollen work (32 sites analyzed by 1942) (Sears, 1942a), only two were published in sufficient detail that they may be utilized today. These were both in northcentral Ohio: Bucyrus Bog located at the edge of his hometown in Crawford County (Sears 1930a) and Mud Lake Bog on the border between Holmes and Ashland Counties (Sears 1931). The Bucyrus Bog deposit is a truncated late-glacial record extending from ca. 14,000 to 9,500 ybp (Sears 1930a, Shane 1989). The site has an interesting palynological history that was studied three times: once by Sears: once by Johannes Iverson, the eminent European palynologist in 1958 when he visited the site with Sears; and once by the author in 1986. In 1989, the author published an historical review of the results of these sequential investigations spanning about 50 years. The central point of the paper was that the results and questions have not significantly changed but, given developing technologies and scientific understanding, some of the answers have.

Pollen-Climate calibration was central for Sears. Researchers now use two major quantitative methods to derive climatic data from pollen data. One is the use of transfer functions pioneered for pollen by Webb and Bryson (1972) and later expanded by Bartlein and others (1984) and Bartlein and Webb (1985). Transfer functions are equations derived from canonical correlation analyses of the relationship of frequencies of modern surface-sample pollen to modern climate data. The results are region-specific equations into which fossil frequencies are substituted to derive a specific climate result for each fossil assemblage. The other is the use of response surfaces which are "... non-linear functions describing the way in which the abundances of taxa depend upon the joint effects of two or more environmental variables." (Bartlein and others 1986 p. 35) (Fig. 3). Fossil assemblages at each level can then be tested against these surfaces to estimate climate parameters.

Sears' paper on Mud Lake Bog (1931) provides a brilliant example of his capacity for innovative thinking for he interpreted his data using a technique similar to that of response surface analysis. He set up a grid with "moist," uncertain and "dry" on one axis, and "cool," uncertain and "warm" on the other. He next assigned each of his major pollen taxa to one point in the grid. For example, *Pinus* is in the "cool-dry" box; *Abies, Larix* and *Tsuga* are in the "cool-moist" box; *Acer*, *Fagus* and *Ulmus* are in the "warm-moist" box; and finally *Carya*, Compositae and Amaranthaceae are in the "warm-dry" box. He then generated a diagram showing each level with the percentages of each climatic indicator (Fig. 4). The resulting graph gives a specific climatic interpretation of the pollen data set. Although the technique Sears used here is less refined than current systems, the goal and the method are conceptually similar.



FIGURES 4 a and b. Fossil pollen of Mud Lake Bog showing distribution according to probable climatic significance noted in table (Sears 1931). Copyright permission of publisher granted.

Pollen analysis of Mud Lake Bog in Ohio. Distribution of fossil pollen at each foot. of level according to probable climate significance (cf. Table II). Three major columns indicate temperature conditions, with moisture conditions under each. Note predominance of warm dry indicators from 5th to 18th foot; warm moist from 18th to 21st; and dry conditions by beginning of 24th foot. Record of 25th foot is telescoped here — for details of cool period see Sears '30, also discussion in text.

TABLE II. *Mud Lake Bog.*
Suggested climatic significance of pollen found.

Moisture	Temperature		
	"Cool"	Uncertain	"Warm"
"Moist"	*Abies* *Larix* *Tsuga*	*Castalia* *Salix* Cyperaceae *Potomogeton* *Sagittaria* *Typha*	*Acer* *Fagus* *Juglans* *Ulmus*
Uncertain	*Picea*	Ericaceae *Populus* Unknown Betulaceae	*Fraxinus* *Quercus*
"Dry"	*Pinus*	Gramineae	Amanthaceae *Carya* Compositae

Synchroniety of European and North American Climate Records

The final example of Sears' broad-based paleoecological thinking is his interest in links between the postglacial climatic records of Europe and North America. He understood that local information could lead to global scale reconstructions as so beautifully shown in Fig. 5 taken from Kutzbach and Webb (1991). Sears established a correlation among North American climate records that indicated one warm/dry period occurring late in the sequences and a "coniferous" dry period early in the sequences (Sears 1932). Then he explored possible correlations of the North American with the European records but came to no definite conclusions (Sears 1935b). His article, "Xerothemic Theory" (Sears 1942b), is an extensive review of past vegetation and climate change. He discusses the major European controversies of the early and late 1800s and briefly mentions the difficulties of establishing a significant correlation between the European and North American records. He concluded that (1) European research demonstrates one or several warm/dry periods depending on what research you accept and (2) the Midwestern North American record supports at least two postglacial warm/dry intervals, specifically a *Pinus* (pine) period and an *Quercus (*oak)-*Carya* (hickory) period.

Wright (1968) reviewed the conflict between Minnesota pollen records that showed a large-scale eastern extension of the prairies before 5,000 ybp, and Ogden's (1966) records from Silver Lake, Logan County, Ohio, showing a prairie extension after 5,000 ybp. Ogden assumed, as did Sears, that increased frequency of *Fagus* (beech) pollen indicates greater moisture, whereas increased frequencies of *Carya* (hickory) and *Quercus* (oak) pollen indicate greater dryness. The mapping work done by Webb and his colleagues over the past 20 years shows complex regional variation in major climatic changes. For example, between 6,000 and 3,000 ybp, northern Minnesota underwent a reversal of the prairie period droughtiness, while the area south of the Great Lakes underwent a slight increase in droughtiness. In 1990, Chumbley and others (1990) published a record from northeastern Iowa supporting much increased droughtiness after 5,000 ybp. Holocene records from across Ohio show a mixed signal. Four pollen records interpreted using response surface analysis indicate pre-5,000 ybp dryness in varying degrees across the state (Shane and others, 2001). However, the Stage's Pond sequence from SE Ohio also shows strong drying post-5,000 ybp. Although Sears' paper (1942b) does not answer

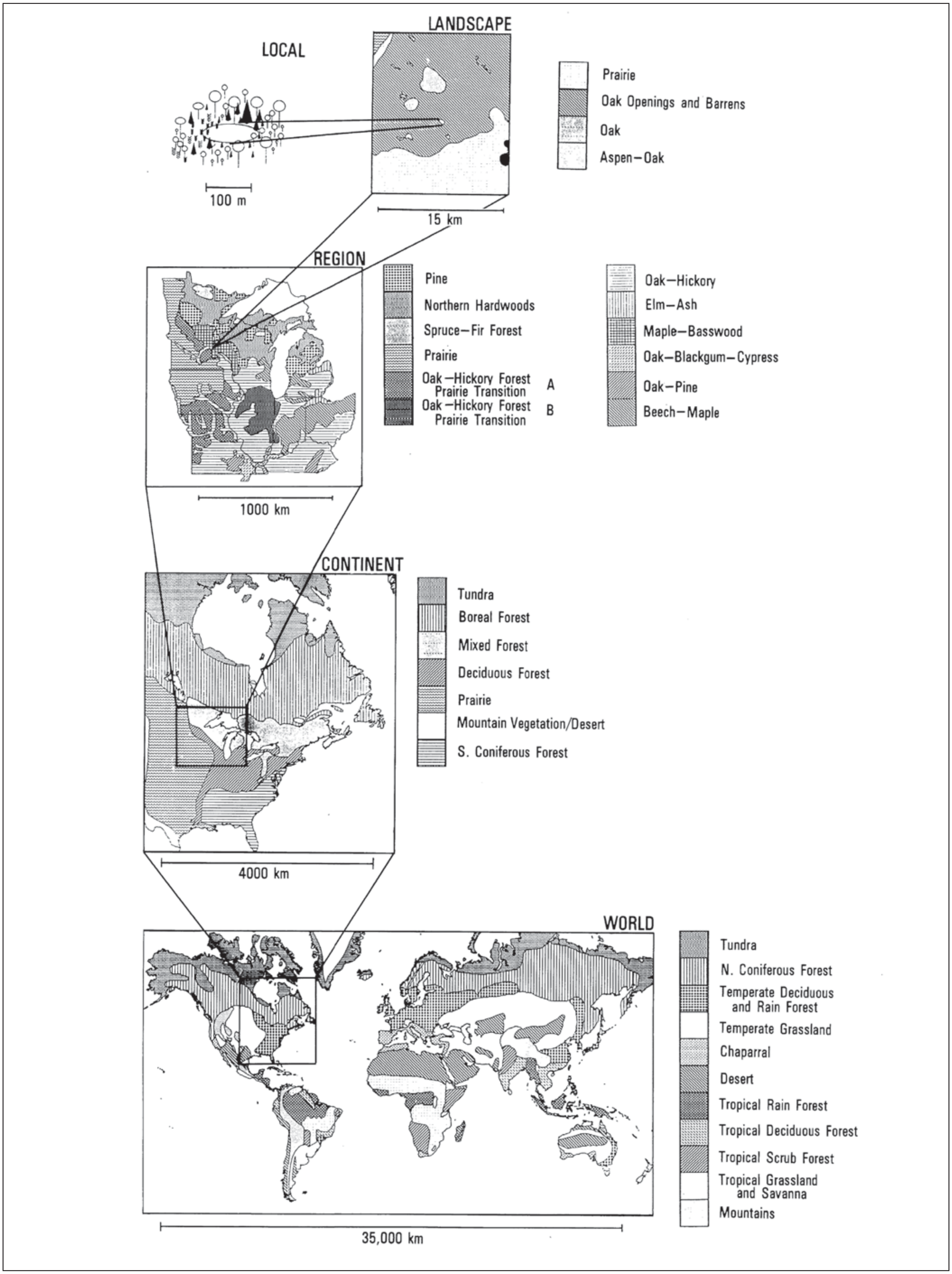


FIGURE 5. Differential spatial scales for recording vegetation patterns from the local setting with site-specific data up to the global scale (Kutzbach and Webb 1991). Copyright permission of publisher granted.

this scientific controversy, it has many statements that we in paleoecology should heed:

> Pollen statistics are most useful when conducted with a full understanding of numerous other sources of evidence. These include local physiographic history, plant succession, human and other biotic factors, sedimentation and floristics. It has already served to identify the diversity of conditions within the continent of Europe, and to act as a brake upon sweeping generalizations regarding synchronous climatic changes. The old cataclysmic idea dies hard. No doubt ... much of the bitter difference of opinion has come from inferring, and expecting to find evidence of changes more sweeping and abrupt than have really occurred. In the operation of climatic change upon plant migration, Asa Gray's words regarding the puzzle of the eastern prairies apply: "there must be a debatable border where slight causes will turn the scale either way." The study of climatic changes seems to the reviewer to be a matter of tracing the slow shifting of such debatable borders through the centuries (Sears 1942b).

CONTRIBTIONS TO METHODOLOGY

Techniques and Pollen Descriptions

While reading the European literature in 1925, Sears became aware of the technique of studying fossil pollen and realized that it could be used to answer questions related to the history of plant communities. Although Auer in Canada (1927, 1930 cited in Stuckey 1990) and Lewis and Cocke in Virginia (1929 cited in Stuckey 1990) had published some North American work a bit earlier, there was no information in the American literature regarding basic descriptions of methods and the pollen grains.. Pollen analysis science was still very new in Europe (von Post 1967, translation from 1916). If it were to be imported successfully to North America, another tool was needed, namely, descriptions of the method and of the major pollen taxa. Without such basic descriptions, researchers could not generate pollen records with consistent data. Thus, his first publication in the discipline was "Common fossil pollen of the Erie basin" (Sears 1930b). This publication included a short summary of the major European literature, a listing of some of the technical problems, field methodology, laboratory and counting procedures and finally a three-page pollen key complimented by a set of notes and *camera lucida* drawings at 700x magnification. The pollen grains of 39 taxa he illustrated (Fig. 6) were beautifully and carefully drawn and represent all the species found most frequently in stratigraphies of glaciated areas in eastern North America.

Presettlement Vegetation Mapping

Stuckey (this volume) presents the second significant methodology Sears developed: the process of using land-survey records to map regional vegetation at, or just prior to, major land clearance by early European settlers. As noted above, one of the key assumptions in studying pollen deposition records is that the recovered pollen reflects or correlates with its origin in the regional vegetation. That relationship is not a simple linear one, and a great deal of research has been done on the subject (Prentice and Webb 1986). Physically, different types of pollen grains have different transport characteristics and different taxa produce different abundances. For example, *Pinus* (pine) pollen is always highly overrepresented in lake sediments, whereas *Abies* (fir) pollen is underrepresented. Researchers interpret up to 5 percent pine pollen to mean no pine trees grew within 50 or more kilometers. On the other hand, 5 percent fir pollen suggests abundant fir trees within the basin. The most successful approach in dealing with these issues has been to sample surface muds in hundreds of lakes across North America and compare the frequencies of the major pollen types with a measure (such as basal area or importance values) of the frequencies of each major taxon (Davis and others 1973, Webb 1974, Delcourt and others 1984, R. Davis and Jacobson 1985, Jackson 1990). Information on distribution of major taxa comes from United States Forest Service's lumbering data and from maps of pre-European settlement vegetation generated with Sears' technique.

International and Interdisciplinary Research Communication

Sears pioneered international and interdisciplinary research communication as a strategy for supporting research and for sharing data and results. In May 1943, Sears mailed from Oberlin College 49 copies of *Pollen Analysis Circular Number 1*. This 4-page document starts with the following statement:

> Because of the suspension of many scientific meetings and increasing handicaps to travel, the undersigned feels greatly the need of a freer interchange of information among those who are interested in pollen analysis in this country. He is therefore ready to underwrite the preparation and mailing of two issues to those who may be interested, after which, if the response seems to justify it, Professor L. R. Wilson of Coe College, Cedar Rapids, Iowa has indicated that he will be willing to underwrite two additional circulars, and Professor J. E. Potzger of Butler University, Indianapolis, Indiana, two more.

Members of the group receiving the first circular were from England, Scotland, Finland, Canada and all over the United States with addresses in geology and botany departments, museums, high schools, private homes, state and federal organizations and an Air Force base. The circulars were mimeographed on inexpensive paper and although existing copies are fragile, a complete set is available at the Limnological Research Center, University of Minnesota. An online version of the circulars is available at http://www.nau.edu/envsci/faculty/ScottAnderson/pollen_and_spore_circulars.htm.

A bibliographic project included almost all the entries concerning vegetational history after the retreat of the last glacial ice. There were 4 issues 1943, 4 in1944, 3 in 1945 and 6 between 1946 and 1949. The last issue (Fig. 7), No. 18, which was distributed in 1954, was 36 pages long and went to at least 200 scientists. By that time it had become unmanageable for the few persons involved to produce these compilations. Subsequently *The Micropaleontologist*, newsletter of the Department of Micropaleontology at the American Museum of Natural History, New York, was slated to incorporate the communications into a similar project. (Apparently this never happened because the newsletter was succeeded in the same year by the journal *Micropaleontology* [http://www.micropress.org/history.html].) The front cover of the last issue, with the 5-year hiatus in publication indicated by the term *grenz-horizont* (Fig. 7), is a glimpse of Sears' sense of humor. In northwestern European bog studies, *grenz-horisont* refers to a supposedly synchronous marker period of drying when peat accumulation stopped (Birks and Birks 1980).

These *Circulars* are significant contributions to the history of pollen studies, full of interesting insights into scientific issues, happenings and politics. Much debated topics included the degree of organization (small and informal *vs.* complex) and settling on the name *Pollen and Spores Circular* designed to indicate that people interested in taxonomy and pre-Quaternary and pre-angiosperm problems were truly part

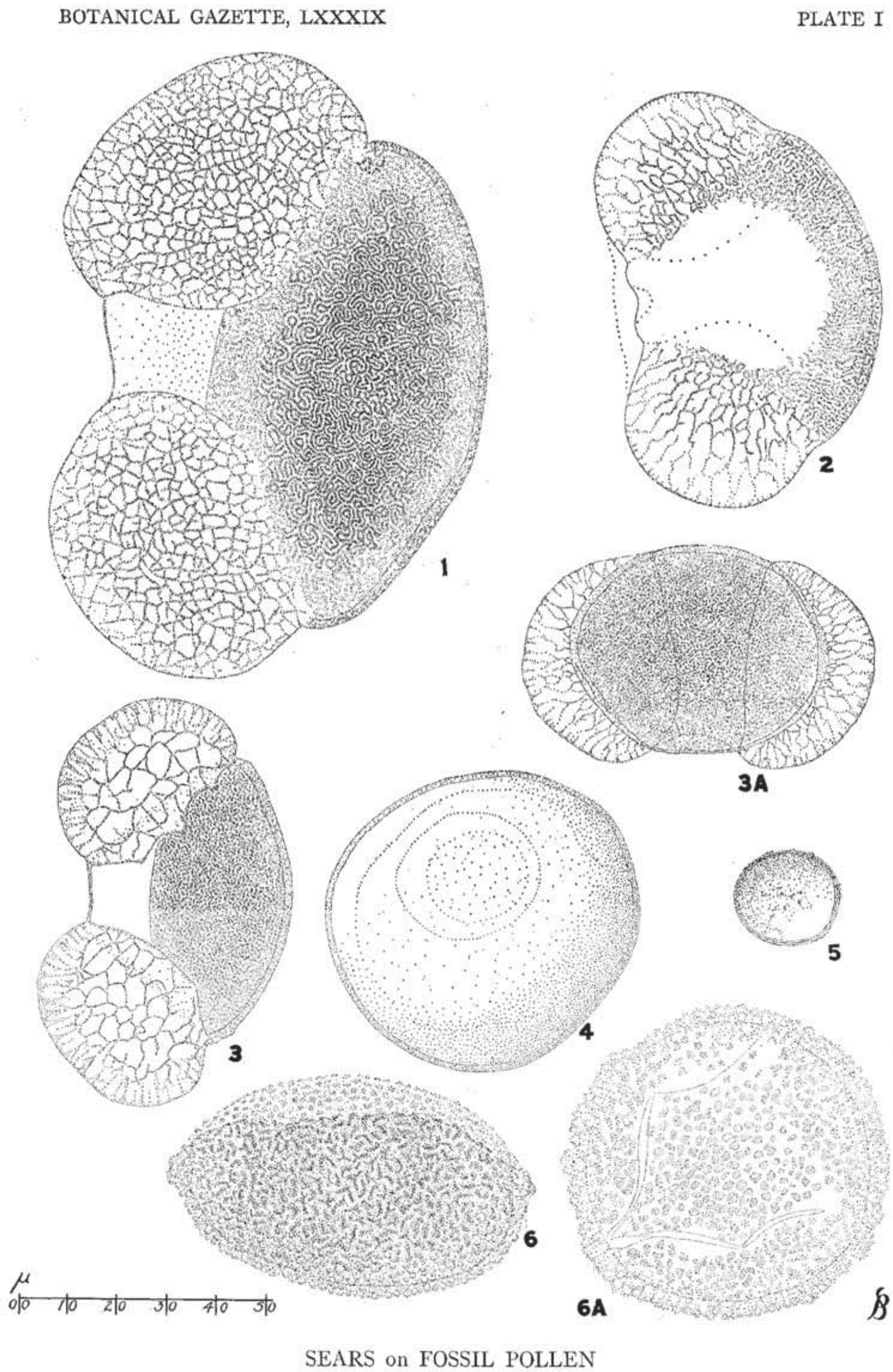
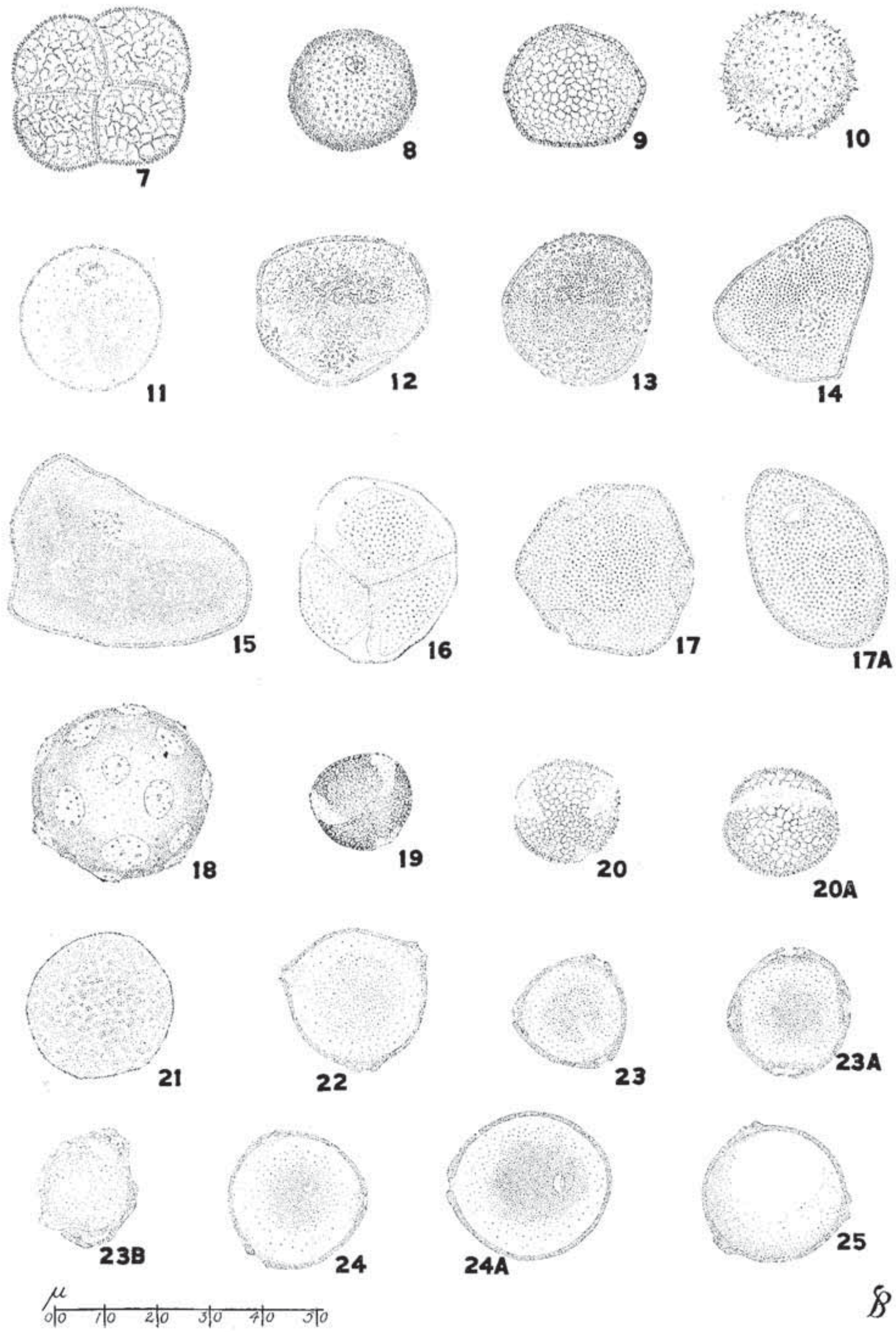


Figure 6 a, b and c. Explanation of Plates I-III of drawings of selected North American pollen grains from Sears (1930b). All figures were drawn by Sears with *camera lucida* and Leitz® microscope; details drawn under oil immersion where necessary. As reproduced here, all represent a magnification of ca. 700 diameters, except Fig. 27, which is about 450. Reproduced here at approximately 60% of original publication size. Bracketed common names of plant species added by editor, not in original paper. Copyright permission of publisher granted.

Figure 6a: PLATE I:
Fig. 1—*Abies balsamea* [Balsam Fir], lateral view;
Fig. 2—*Picea mariana* [Black Spruce], lateral view, showing subconical air sacs;
Fig. 3—*Pinus strobes* [Eastern White Pine], lateral view; fig. 3a, top view;
Fig. 4—*Larix deciduas* [European Larch], showing globule of resinous contents;
Fig. 5—*Juniperus virginiana* [Eastern Redcedar]; *Thuja* [Northern Whitecedar] very similar;
Fig. 6—*Tsuga Canadensis* [Eastern Hemlock], lateral view (ventral side up) showing coarse projecting dorsal coat and thin ventral one; fig. 6a, ventral view;

BOTANICAL GAZETTE, LXXXIX PLATE II



SEARS on FOSSIL POLLEN

Figure 6b: PLATE II:
Fig. 7.—*Typha latifolia* [Common Cattail], typical close tetrad, but grains often occur singly;
Fig. 8.—*Sparganium* sp. [Bur-reed] showing single roughly operculate pore and pebbly surface;
Fig. 9—*Potamogeton richardsonii* [Richardson's pondweed];
Fig. 10—*Sagittaria* sp [Arrowhead];
Fig. 11—*Glyceria borealis* [Northern Mannagrass], single operculate pore and smooth surface;
Fig. 12—*Carex vulpinoides* [Foxsedge], showing, with the next three, typical granular exits of *Cyperaceae*;
Fig. 13—*Eriophorum virginicum* [Tawny Cottongrass];
Fig. 14—*Eleocharis palustris* [Common Spike-rush];
Fig. 15—*Scirpus americanus* [Olney's Bulrush];
Fig. 16—*Juncus effuses* [Soft rush];
Fig. 17—*Tilia Americana* [Basswood], polar view;
Fig. 17a, equatorial view;
Fig. 18—*Liquidambar styraciflua* [American Sweetgum];
Fig. 19—*Platanus occidentalis* [American sycamore];
Fig. 20, 20a—*Salix sericea* [Silky Willow];
Fig. 21—*Populus deltoids* [Eastern Cottonwood];
Fig. 22—*Betula lutea* [Yellow Birch];
Fig. 23, 23a, 23b.—*Alnus incana* [Speckled Alder];
Fig. 24, 24a.—*Corylus americana* [American Hazelnut];
Fig. 25, 25a.—*Ostrya virginiana* [American Hophornbeam];

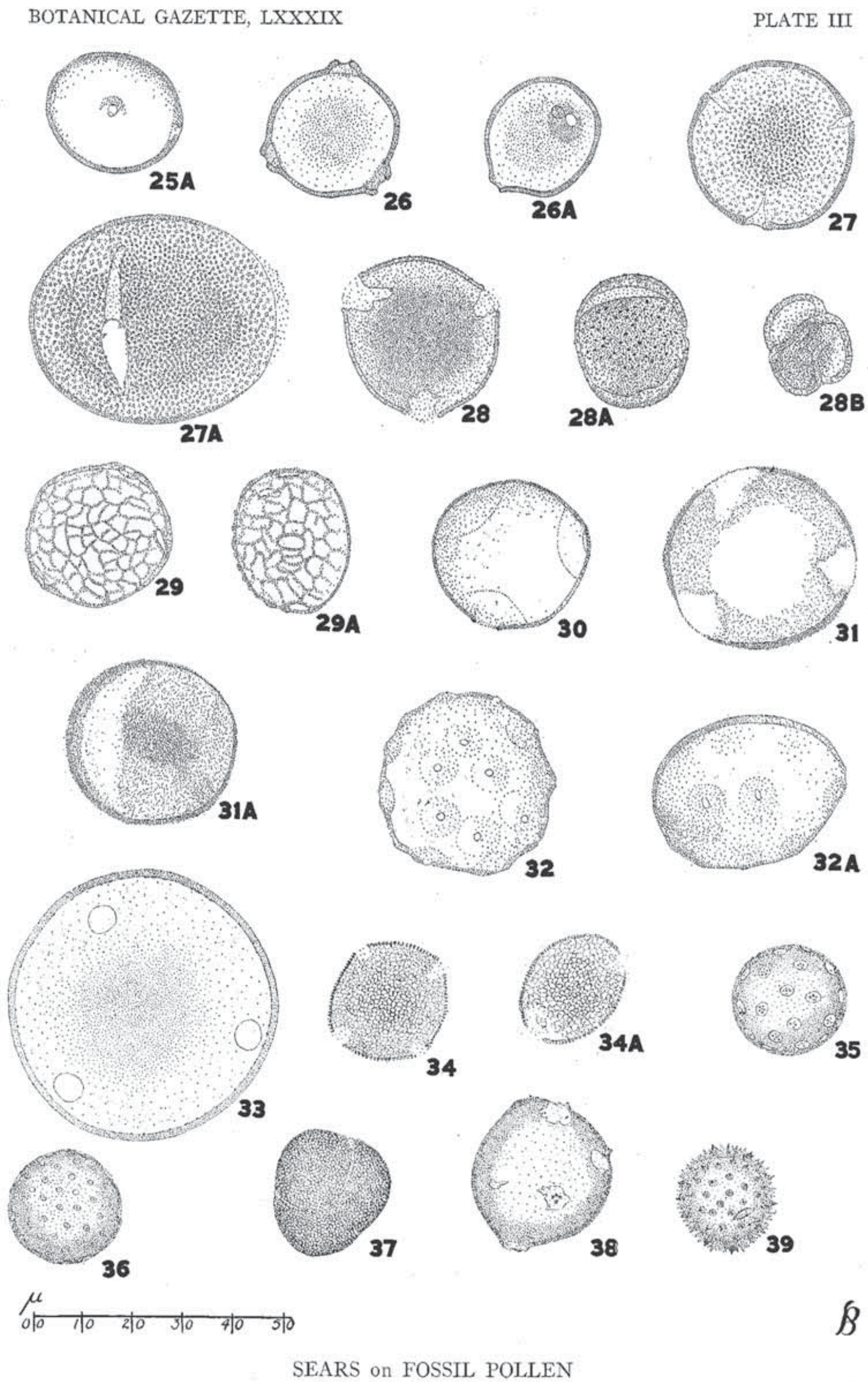


Figure 6c: PLATE III:
Figure 26, 26a.—*Carpinus caroliniana* [American hornbeam];
Figure 27—*Fagus grandifolia* [American Beech], polar view (X450); fig. 27a, equatorial view (X700);
Figure 28—*Quercus alba* [White Oak];
Figure 28a, Q. *macrocarpa* [Bur Oak];
Figure 28b, Q. *rubra* [Northern Red Oak];
Figure 29, 29a—*Ulmus Americana* [American Elm];
Figure 30—*Celtis occidentalis* [Common Hackberry];
Figure 31, 31a—*Acer saccharum* [Sugar Maple];
Figure 32, 32a—*Juglans nigra* [Eastern Black Walnut];
Figure 33—*Carya ovata* [Shagbark Hickory], polar view;
Figure 34, 34a—*Fraxinus lanceolata* [Green Ash];
Figure 35—*Amaranthus retroflexus* [Common Amaranth];
Figure 36—*Chenopodium* sp [Goosefoot];
Figure 37—*Rumex brittanica* [British Dock];
Figure 38—*Plantago rugelii* [Blackseed plantin];
Figure 39—*Ambrosia psilostachya* [Cuman Ragweed].

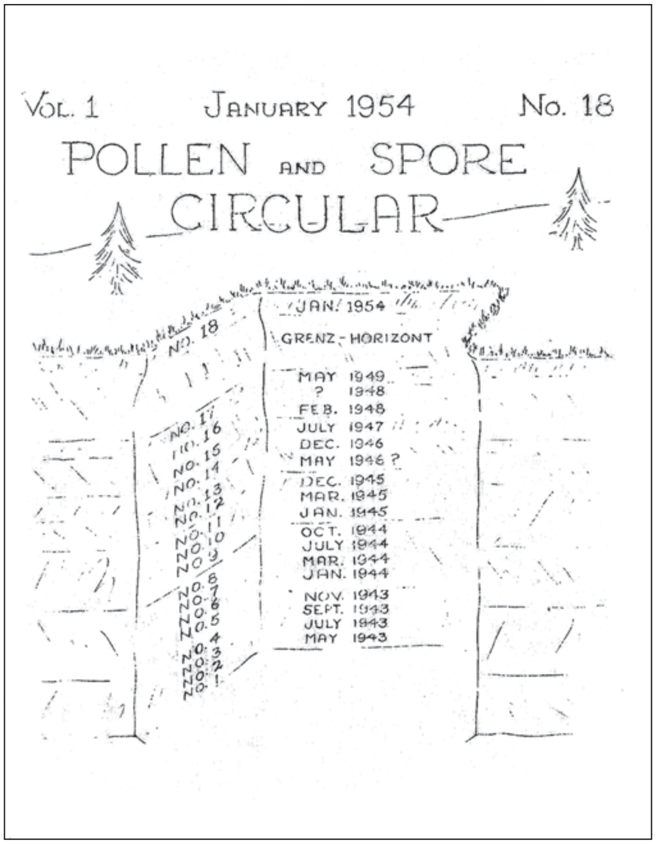


FIGURE 7. Cover of *Pollen and Spore Circular No. 18*, the final issue. Entire set available at http://www.nau.edu/~envsci/faculty/ScottAnderson/pollen_and_spore_circulars.htm

of the group. The *Circulars* are full of personal touches from many of the leading scientists of the day. The letter dated 15 January 1945 by the renowned British scientist Harry Godwin (later Sir Henry) in *Pollen and Spore Circular No, 10* expressed the difficulties of scientific communication during World War II most poignantly and shows the high value of what Sears accomplished with this project.

> I have been getting the pollen analysis circulars quite regularly and they give me a lot of pleasure, and are useful in indicating what is going on, and in giving *candid and informal opinions such as folk would never publish* [author's emphasis]. That is why on the whole I like the show as it now is, and am rather against a formal organization. (p. 3)
>
> When our pollen analysis community has got integrated and the world will let us do it I should dearly like to raise the wind enough to come over to the States to take part in a meeting about all the matters we have in common. (p. 3)

PALEOECOLOGICAL RESEARCH AND GLOBAL CLIMATE CHANGE

In the first two or three decades of its history, the scientific community viewed the discipline we now call Quaternary paleoecology skeptically. Although the field was viewed as promising in that novel approaches to taxonomic and biogeography problems were being developed, colleges and universities were hiring few paleoecologists. Now paleoecological research is critical to understand the increasing changes in our atmosphere and well as whether this change is occurring rapidly or gradually. The paleoecological records from hundreds of specific places across the globe provide the ground truth, or data against which climate modeling research can be tested (Kutzbach and Webb 1991)(Fig. 5). Thus, paleoecological research is of increasing importance as governments worldwide grapple with policies to address global climate change. Sears' book *Deserts in the March* (1935a), inspired by the devastation of the Dust Bowl, was an attempt to explain to the general public the impact of human activities on global environments. Today the data and analyses generated by paleoecological studies are one part of building an inderstanding of the impact of global climate change on ecosystems and humans.

Author's Chronological Note. This paper was prepared for the 1991 symposium honoring Paul B. Sears. It has undergone only minor revisions since then. Updating is limited because the basic conclusions of the paper have not changed.

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